

RHIC Energy Scan

Nu Xu

Lawrence Berkeley National Laboratory

B. Jacak, V. Koch, B. Mohanty, P. Sorensen ...

INT Workshop on “QCD Critical Point”

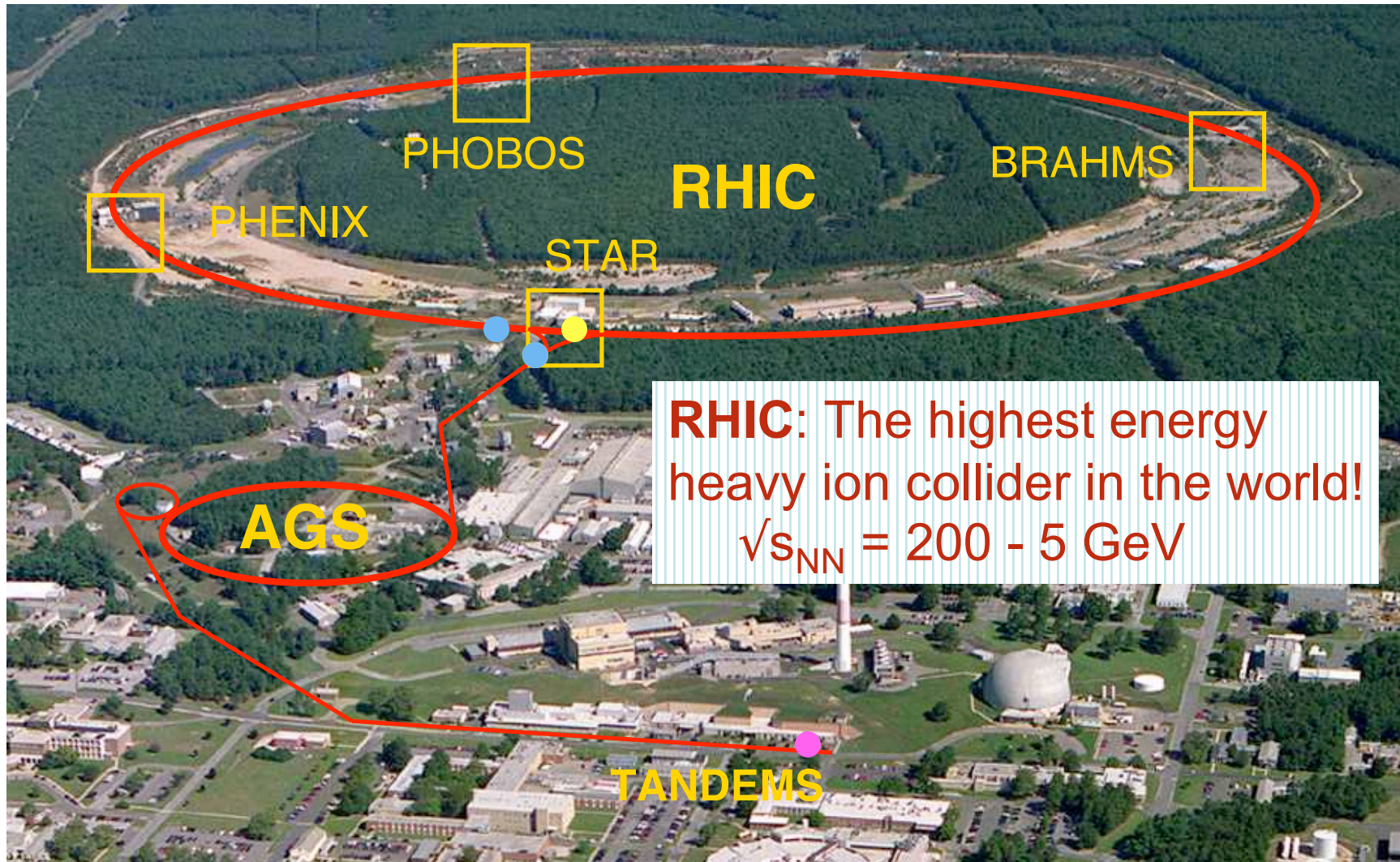
V. Koch, G. Roland, and M. Stephanov

July 28 - Aug. 22, 2008

<http://int.phys.washington.edu/PROGRAMS/08-2b.html>

Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY



Animation M. Lisa



sQGP and Phase Diagram

RHIC at 200 GeV Au+Au collisions, strongly interacting matter formed:

Jet energy loss R_{AA}

Strong collectivity v_2

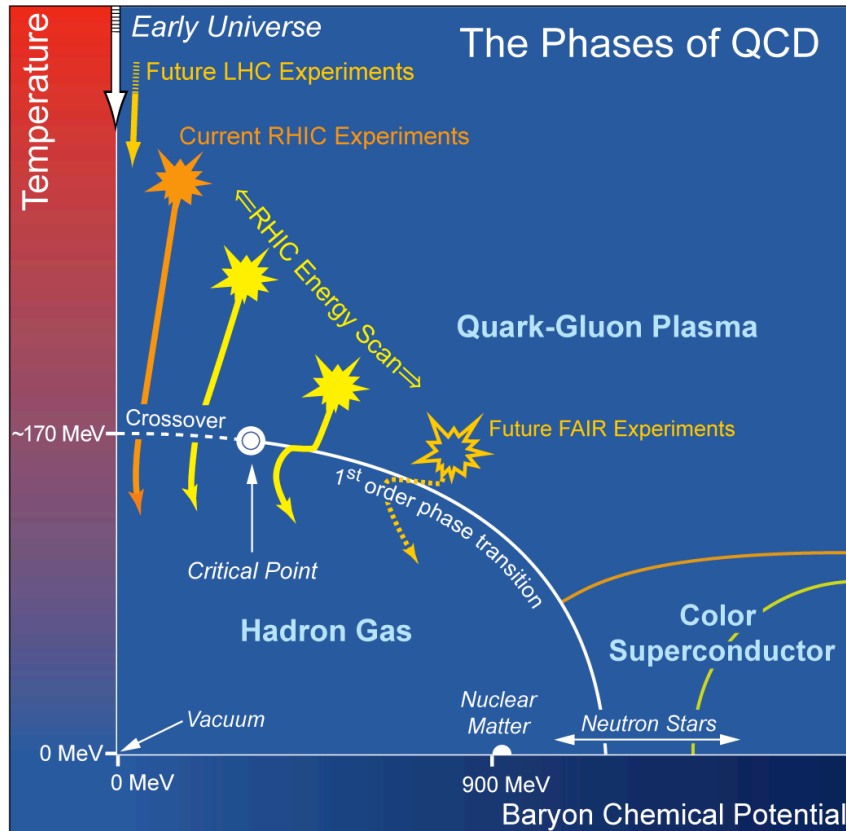
Hadronization via coalescence - n_q scaling

Questions:

When (at which energy) does this transition happen?

What does the QCD phase diagram look like?

The QCD Critical Point



- LGT prediction on the transition temperature T_c is robust.

- LGT calculation, universality, and models hinted the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

*** Thermalization has been assumed**

M. Stephanov, K. Rajagopal, and E. Shuryak, *PRL* **81**, 4816(98)

K. Rajagopal, *PR* **D61**, 105017 (00)

<http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf>



PHENIX and STAR's Plans

$\sqrt{s_{NN}}$ (GeV)	PHENIX	STAR	
62.4	✓		
39	✓	✓	
28	✓	✓	
22.4*	✓		
17.3		✓	
12.3		✓	
8.6		✓	
7.7		✓	
6.1		✓	
5.0		✓	



BNL PAC Recommendations

May 8 - 9, 2008

Run 09-10:

1. Longitudinally polarized proton-proton collisions at $\sqrt{s} = 200$ GeV with 60% average polarization for 10-12 weeks, sufficient to record an integrated luminosity of about 25 pb^{-1} in PHENIX and about 50 pb^{-1} in STAR.
2. High luminosity Au+Au collisions at $\sqrt{s} = 200$ GeV for 8-10 weeks, corresponding to an integrated luminosity of $1.2\text{-}1.4 \text{ nb}^{-1}$ in PHENIX, to exploit the capabilities of its Hadron Blind Detector (HBD). This will allow both a high precision measurement of the low mass di-lepton spectrum in PHENIX and STAR, and development of transverse stochastic cooling of the Au beams. In addition, it will enable STAR to exploit its new DAQ capability in a high statistics run.
3. Longitudinally polarized proton-proton collisions at $\sqrt{s} = 500$ GeV for 5 weeks to allow beam development and commissioning by C-AD, a first measurement of W boson production in PHENIX, and background studies in STAR.



BNL PAC Recommendations

May 8 - 9, 2008

Run 11-13:

2.2.3. Heavy ion collisions at lower energies

There are multiple compelling motivations for running RHIC at lower energies. The search for the QCD critical point is a “must do” experiment. Beyond this specific search, the collision energy dependence of various signature characteristics such as quasi-ideal hydrodynamic flow and jet-quenching should be determined. To date, however, the PAC has not seen a compelling presentation of the key observables and their potential physics impact for this measurement program.

In the view of the PAC, the experiments must define a strategic approach to the energy scan program, with a first exploratory run of order 8-10 weeks that will indicate whether and how to further explore this region with additional running in later years. For both experiments, the essential set of energies and the details of the physics implications (beyond projected statistical uncertainties) from different data sets need to be developed. This will require input from the theory community. The upcoming INT workshop provides a timely opportunity for the experimental and theoretical communities to work together toward this goal. This input is required to determine the future run duration, energy range, and number of energy points as correlated with physics potential (both for discovery and for further quantification).



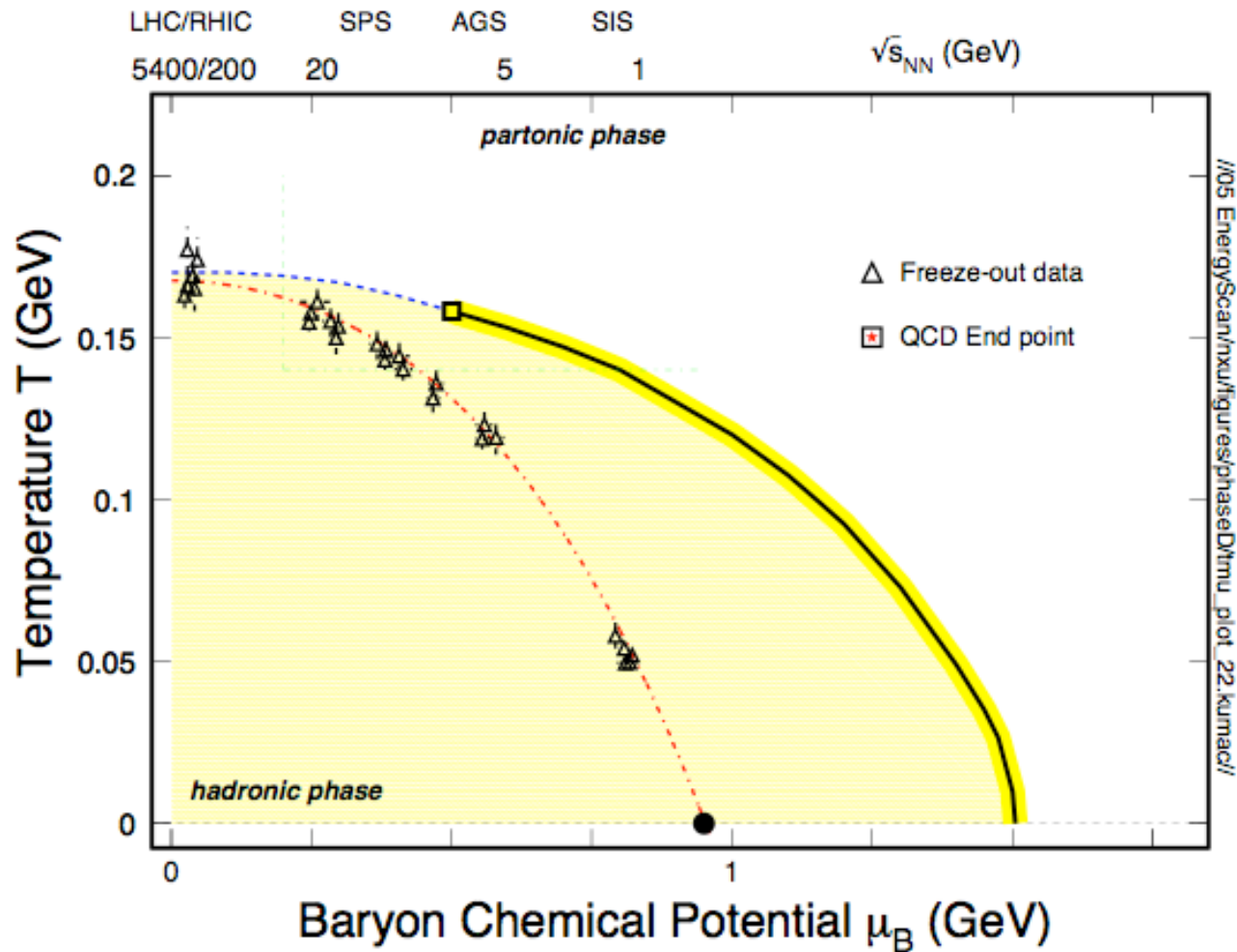
BNL S&T Review Comments (draft)

July 7 - 8, 2008

Comments:

- RHIC scientific output, by any measure, has been outstanding in 2007/2008.
- The PHENIX and STAR groups at BNL have been extraordinarily successful in producing forefront physics while taking leading roles in the development of hardware.
- The new measurements made by PHENIX and STAR have already had international impact and have stimulated many new theoretical investigations.
- **The STAR collaboration is encouraged to develop the priority physics observables for running below the current injection energy.**

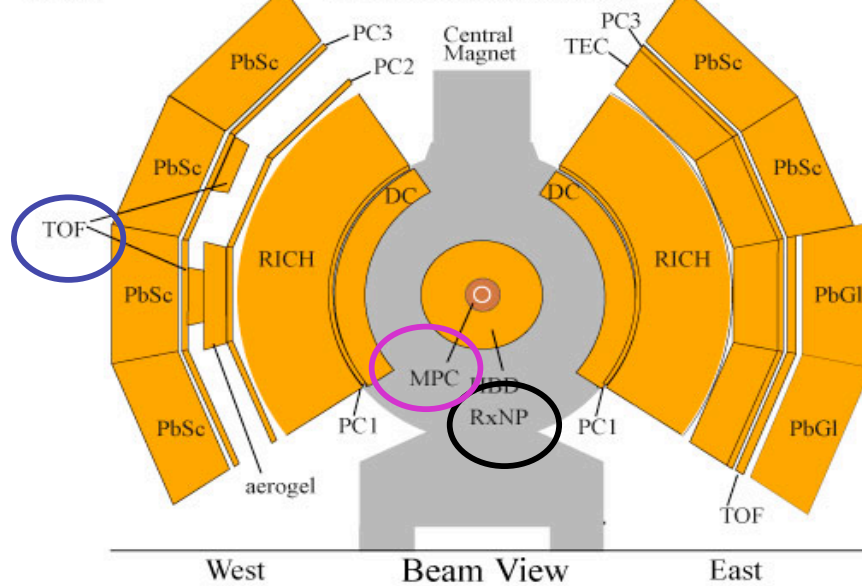
QCD Phase Diagram



PHENIX Detector Status

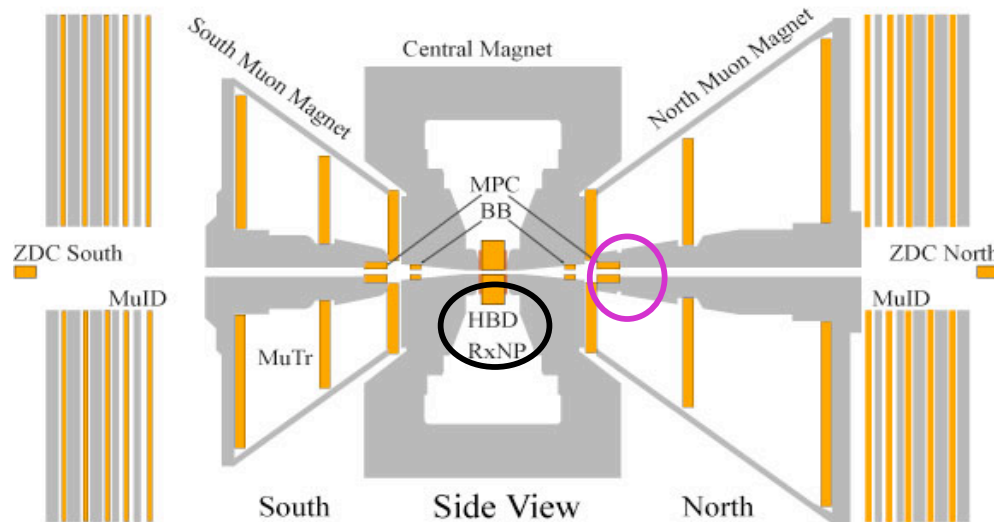
2007

PHENIX Detector



**Hadron Blind,
Reaction Plane
detectors**

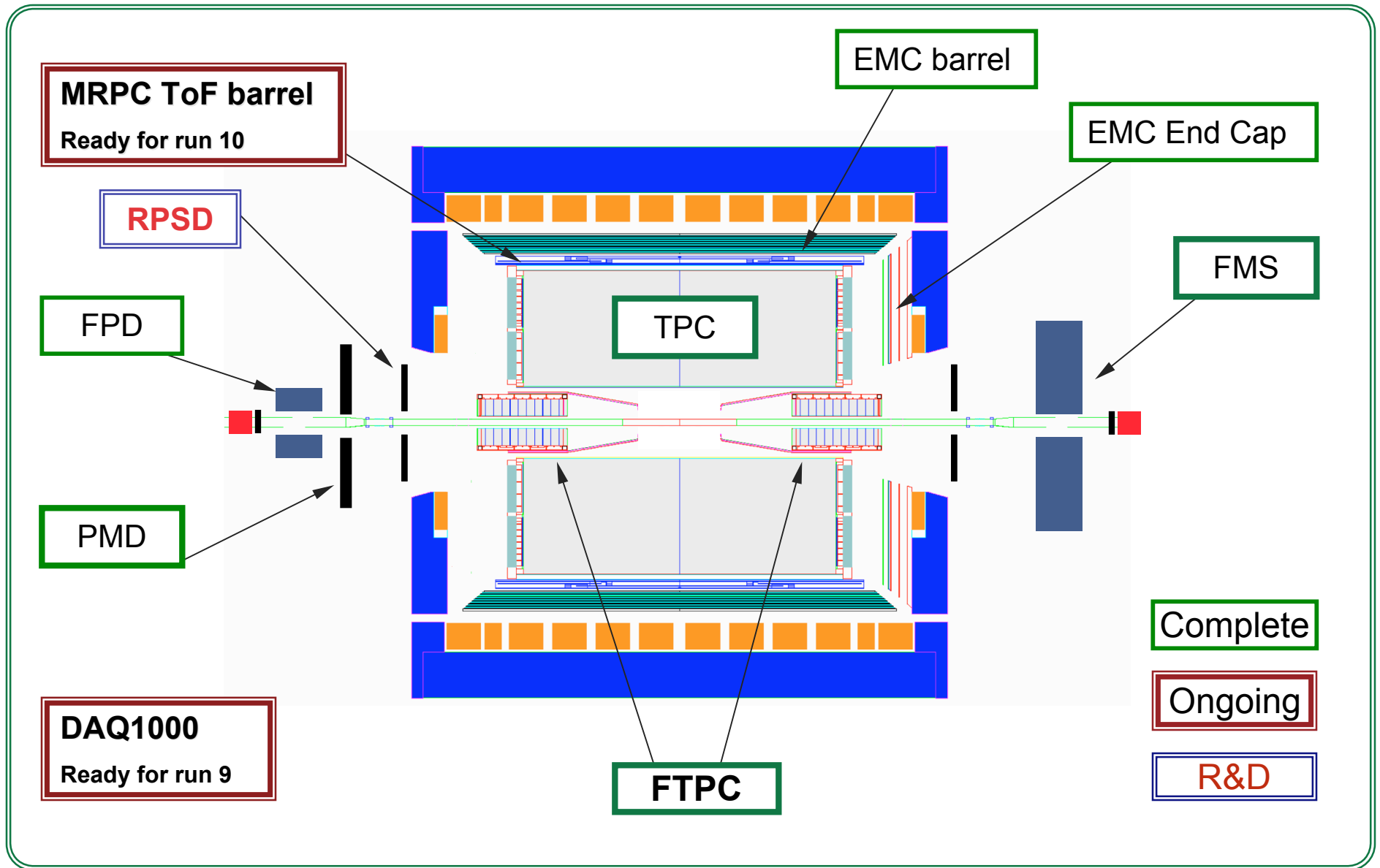
**Muon Piston
Calorimeter (N & S)**



**Good PID
Fast**

Small acceptance

STAR Detector (2010)





Predictions and Observables

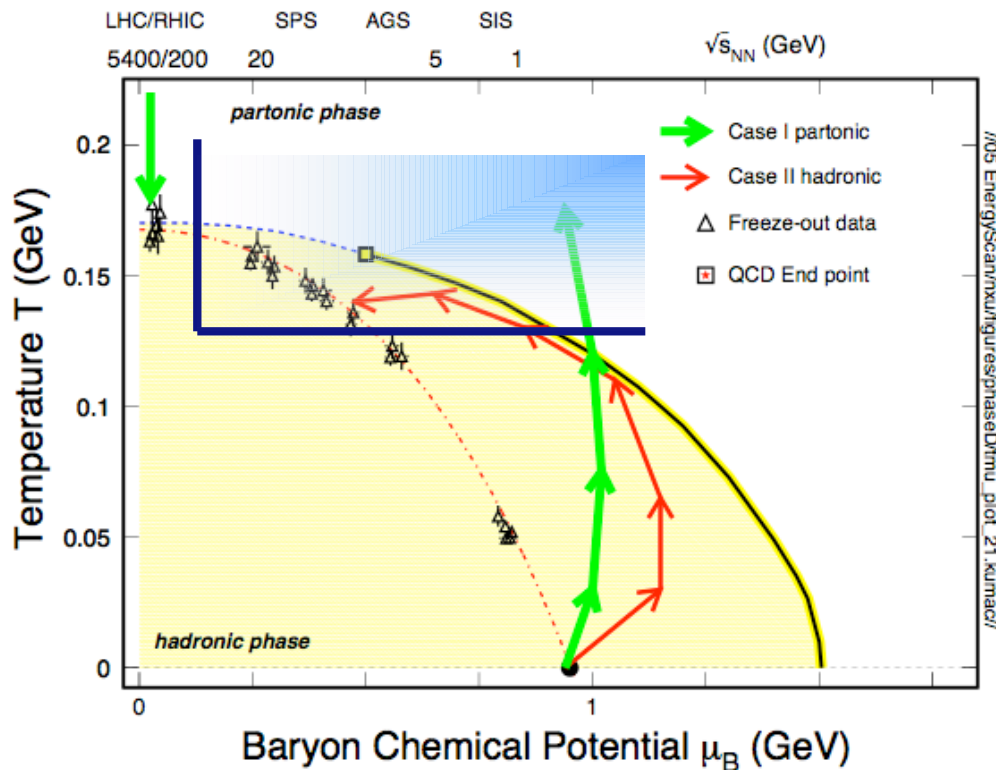
What to measure?

- Predictions?
- Observables?

What have been ruled out?

- Understanding?
- New observables?

Lattice Results* Indicate:



Prediction the cross-over of T_C at zero chemical potential is most likely correct.

Most likely the region for the QCD critical point*:

$$T \geq 140 \text{ MeV}$$

$$\mu_B \geq 200 \text{ MeV}$$

$$\Rightarrow$$

$$40 \geq \sqrt{s} \geq 5 \text{ GeV}$$

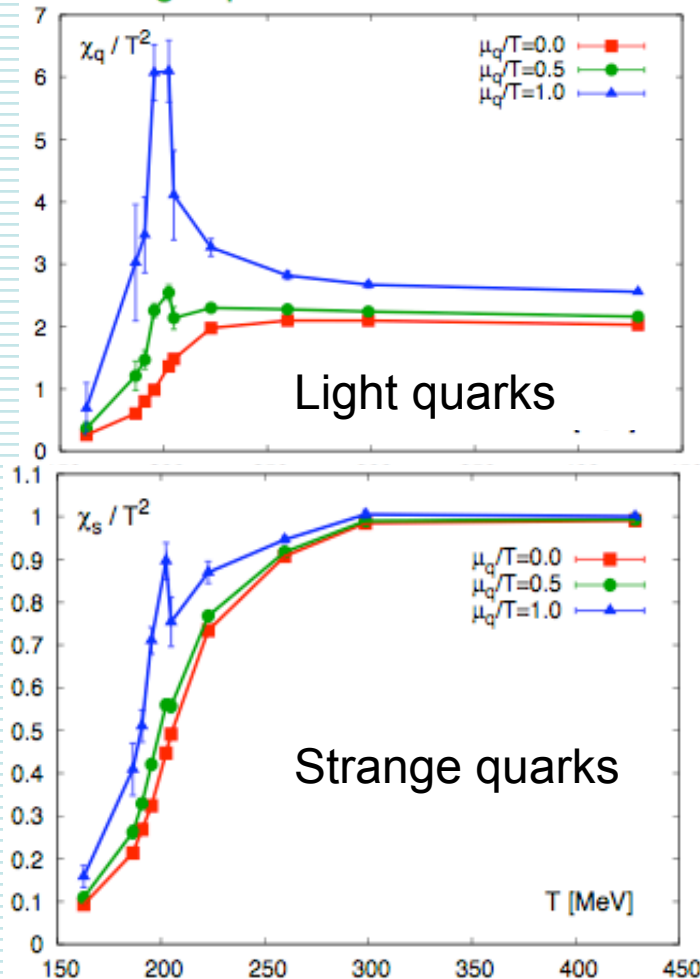
• In all Lattice calculations, global thermalization are assumed.

- S. Gupta et al.

Experimental Observables:

Quark Number Susceptibility

F Karsch, 2008



On Lattice: a spike in susceptibility means long range correlation at the critical point.

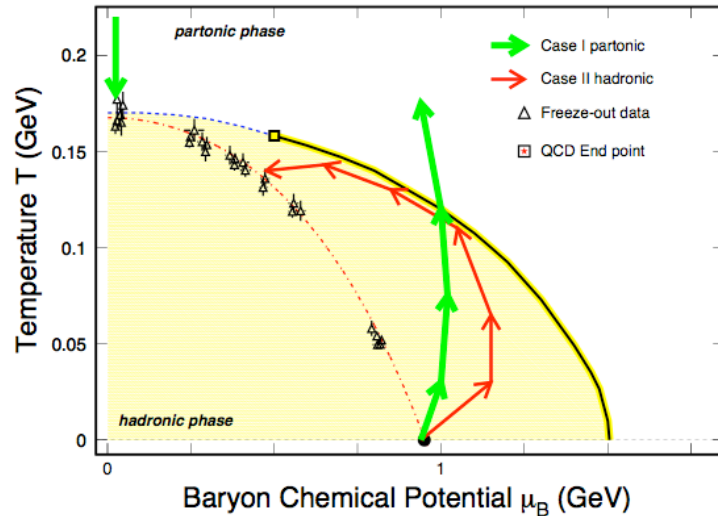
The equilibration of the medium is assumed in all Lattice calculations.

In Experiment: measure the correlation function of baryons or protons.

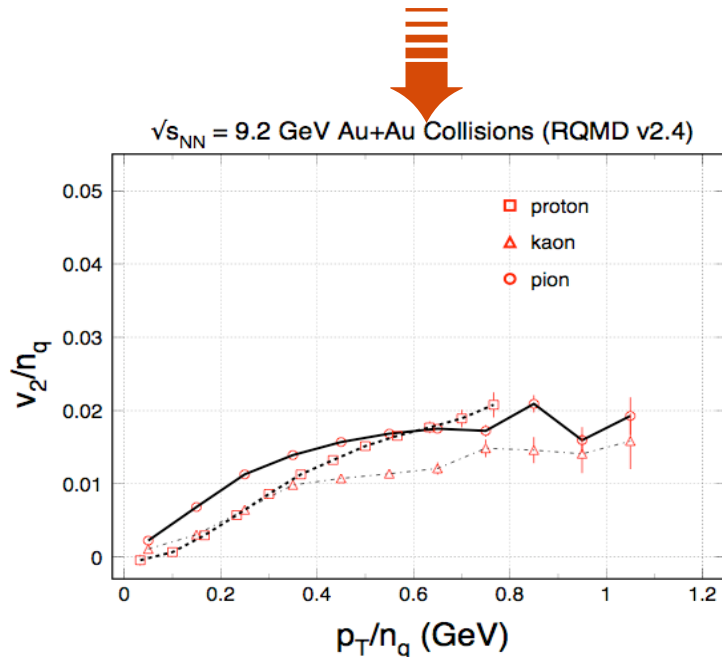
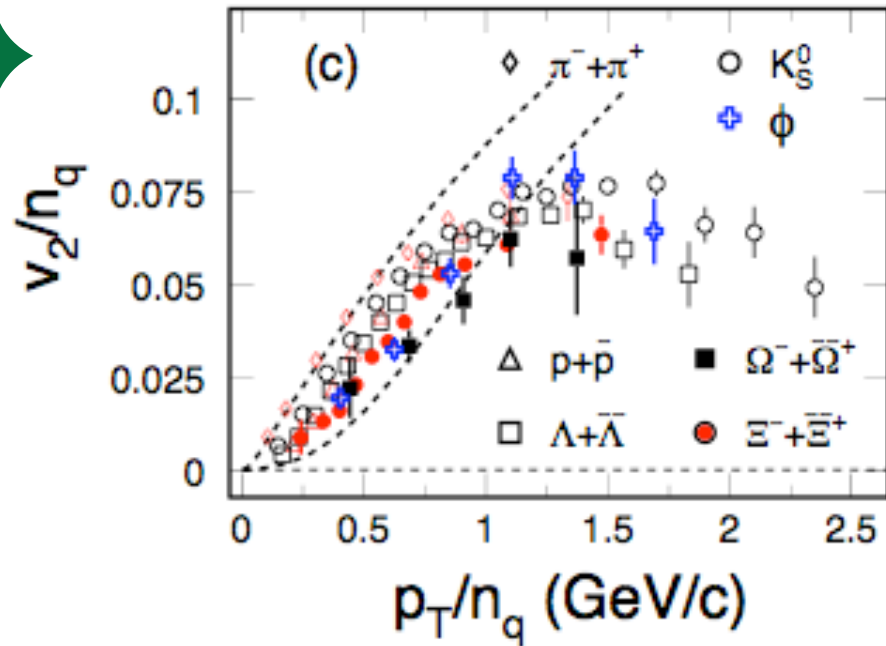
$$K_B = \frac{\langle N^4 \rangle - 3\langle N^2 \rangle^2}{\langle N^2 \rangle}$$

- *Kurtosis analysis for protons*
- *proton-proton correlations*
- *d/p => Baryon phase density*

Partonic vs. Hadronic Phases



$\sqrt{s_{NN}} = 200$ GeV Au + Au Collisions at RHIC (IV)



- $m_\phi \sim m_p \sim 1$ GeV
- $ss \Rightarrow \phi$ not $K^+K^- \Rightarrow \phi$
- $\sigma_{\phi h} \ll \sigma_{p\pi, \pi\pi}$

In the hadronic case, no number of quark scaling and the v_2 of ϕ will be small.

Two Step Approach

$\sqrt{s_{NN}}$ (GeV)	PHENIX	STAR	
62.4	✓		
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17.3		✓	
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5.0		✓	

Step I: First RHIC energy scan: FY10, 8-10 weeks.
4 weeks above the injection energy and 5-6 week below.

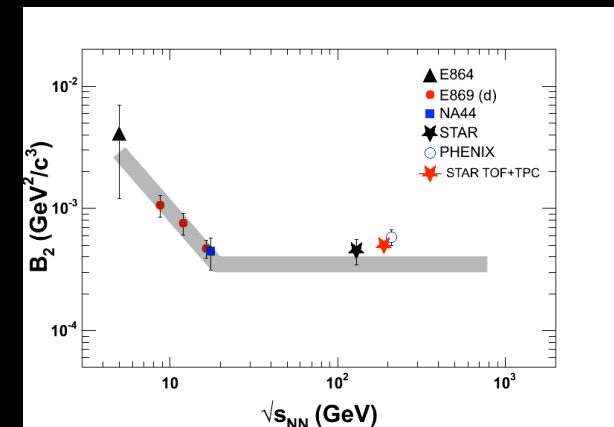
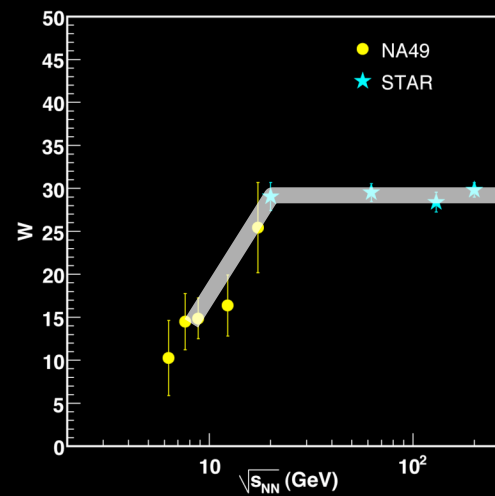
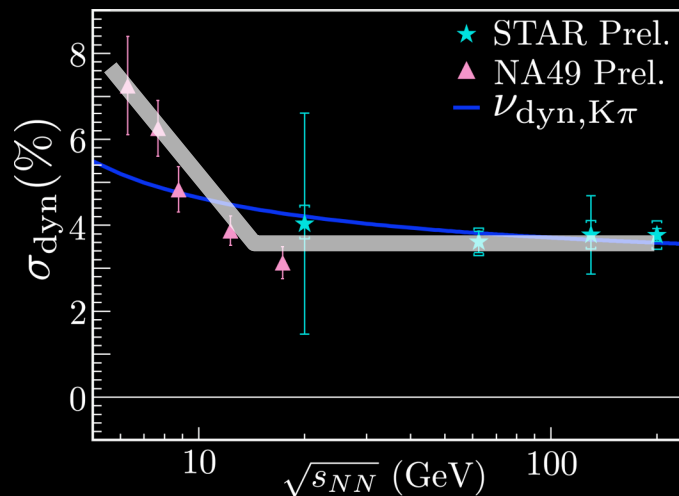
Energy Dependence

From Westfall and Sorensen

K/pi fluctuations

Balance function

Baryon density



Note: Freeze-out T_{fo} , β_T , v_2 , ... vs. energy also show the dramatic change between $\sqrt{s} = 5$ and 20 GeV.



Two Step Approach

Step I:

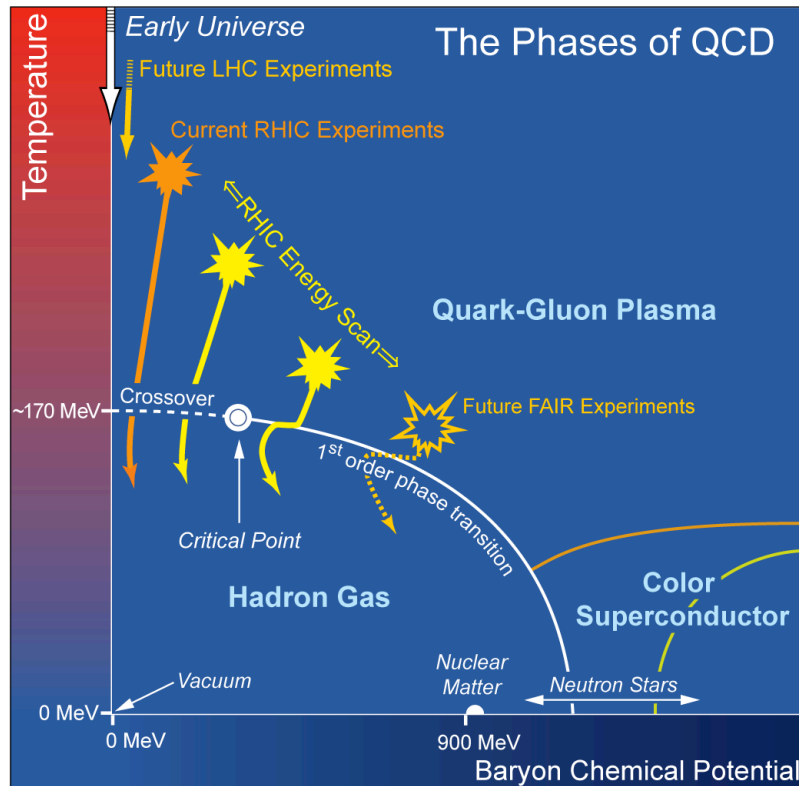
First RHIC Energy Scan: FY10, 8-10 weeks.
4 weeks above the injection energy and 5-6 week below.

Strategy: (a) disappearance of sQGP signal
(b) appearance of critical behavior

Step II: FY12 (or later)

Strategy: Focus on the region where the (a) and (b) cross each other.

Search for QCD Critical Point (STAR BUR09)



STAR Beam User Request FY10

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	Rate [Hz]	Goal [Events]	Duration [Days]
5.0	550	0.5		7
6.1	491	1.4	1 M	20
7.7	410	2.7	2 M	20
8.6	385	4	2 M	15
12.3	300	10	5 M	15
17.3	229	25	10 M	12
27	151	30	10 M	7
39	112	50	10 M	6

Key measurements:

- (1) All PID hadron spectra and v_2
- (2) K/π , $\langle p_T \rangle$... fluctuations

Strategy:

- (1) From high to low energy, disappearance of high energy density phenomena (controlled experiment)
- (2) Cover SPS range $\sqrt{s_{NN}} = 5 - 20$ GeV, look for the onset of de-confinement



2	C.P.	- anti-p/p (y_T)		
3	C.P. [2]	$\langle p_T \rangle$, $\langle N_{ch} \rangle$, $\langle K/\pi \rangle$, $\langle p/\pi \rangle$, $\langle p/K \rangle$,		
4	1 st Order, light σ [3,4]	Collapse of proton v_1 and v_2		

Predictions		Observables	# of events
1	C.P. (lattice light quark susceptibility χ_q)	Parity V. [5]	Analysis for protons
		C.P.; phase transition(?)	Correlations
		Partonic vs. hadronic	2-dimensional correlation analysis $\Delta\phi - \Delta\eta$
		???	PID hadron and ϕ -meson v_2
2	C.P.	Balance-function	
	P.T.	2-dimentional correlation analysis $\Delta\phi - \Delta\eta$, long range correlations	
	Partonic vs. hadronic phase	PID hadron and ϕ -meson v_2	

Signals		Observables	# of events	
1	C.P. (lattice light quark susceptibility χ_q , 1 st)	<ul style="list-style-type: none"> - <i>Kurtosis analysis for protons</i> - <i>proton-proton correlations</i> - <i>Kan-proton correlations</i> - <i>d/p => Baryon phase density</i> 		
2	C.P.	- anti-p/p (y_T)		
3	C.P. [2]	$\langle p_T \rangle$, $\langle N_{ch} \rangle$, $\langle K/\pi \rangle$, $\langle p/\pi \rangle$, $\langle p/K \rangle$,		
4	1 st Order, light σ [3,4]	Collapse of proton v_1 and v_2		
n+1	Parity V. [5]			
n+2	C.P.; phase transition(?)	- 2-dimentional correlation analysis $\Delta\phi - \Delta\eta$		
n+3	Partonic vs. hadronic	PID hadron and ϕ -meson v_2		
n+4	???	Balance-function		